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Nelson Kimball Rogers

A STUDY OF WORK-TIME DISTRIBUTION CHARACTERISTICS AND THEIR RELATIONSHIP TO DELAY TIME DISTRIBUTION CHARACTERISTICS FOR SEVERAL OPERATORS DURING SIMILAR WORK PERIODS

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Nelson Kimball Rogers

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A STUDY OF

WORK-TIME DISTRIBUTION CHARACTERISTICS

AND THEIR RELATIONSHIP TO

DELAY TIME DISTRIBUTION CHARACTERISTICS

FOR SEVERAL OPERATORS DURING SIMILAR WORK PERIODS

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SUMMARY

The purpose of this study was two-fold. Studies of work time frequency distributions derived from sample sizes larger than five hundred were obtained in order to determine the general nature of the parameters of such distributions and the results were then compared with previous research in this area of work measurement.

Delay time distributions were obtained in order to determine the general nature of their parameters and these results were studied to find out if they had any relationship to the work-time distributions obtained during similar observation periods.

A manual, repetitive, worker controlled, short cycled operation was observed. Observations of three operators for two consecutive hours each were made, followed by a replicate observation period for the initial operator observed.

Cycle and delay times were recorded on a Milliminute Timer developed in conjunction with this work. Various distributions were obtained as follows:

Frequency distributions of all cycle times.

Frequency distributions of cycle times remaining after all cycles containing internal delays were removed.

Frequency distributions of external delay times.

Frequency distributions of internal delay times.

Parameters were obtained for these various distributions and statistical tests were made to determine their significance.

The results substantiated previous work in the analysis of work-time distributions as the work-time distributions obtained in this study were all positively skewed and more peaked than the normal curve.

The mean, variance, and measures of skewness and peakedness decreased when cycles containing internal delays were omitted from the study.

External delays exceeded internal delays in both number and mean length.

Within the limitation of the small sample sizes of delays obtained, the frequency distributions of delay times did not differ significantly in measures of skewness and peakedness from the normal curve.

Work-time distribution means for individual operators varied significantly from hour to hour in the observation period, but the standard deviation of the individual operators did not show significant variation.

Further investigation should be made concerning these relationships in order to more properly determine the salient features of a pure work-time distribution.

CHAPTER I

INTRODUCTION

Work Measurement.—Measurement of work involving human effort is not a science. Methods of determining the length of time for a person to accomplish a given task are plentiful. After seventy years of development, not one of these methods has completely satisfied the criteria of reliability and precision necessary in an exact science. Regardless of the method in current use, any person engaged in work measurement must honestly agree with Abruzzi when he said, "We need objective principles and procedures so that the estimates we make and the action we take will be sound in a scientific sense." (1)

The traditional system of work measurement depends upon observation of a person performing a given task with a given set of motions or motion patterns. The length of time to perform this task is timed by one of the many mechanical methods available, and the worker's speed or degree of effort is related in some manner to a concept of normality. An allowance is then made for delays or non-productive time inherent in the given task, and through mathematical procedures a standard is set for the given task. Systems have been devised that combine or attempt to eliminate some of these elements or steps in the work measurement procedure, but none have met with acceptance in the scientific sense that Abruzzi or anyone else desires.

Wilkinson berates those active in the field of work measurement when he says, "They have, in fact, taken pains to reduce the mathematical element of Time Study to a minimum, and to refine subjective techniques as a substitute for objective determinations." (2) It is possible to observe work objectively. It is possible to time work objectively. There is general agreement that errors in these two steps are not large and that modern technology can reduce these errors further.

Insuring that a task is performed according to a given set of motions, at a consistent speed, without interruptions, is impossible, if a human being is performing this task. Variation in these three elements is the crux of the problem of work measurement. When all work is performed by machines, these three problems will be eliminated. Until that time, those involved in work measurement must attempt to relate them in the most objective manner possible. It is hoped that such a relation may someday be found by using a mathematical model. Contrary to Wilkinson's assertion, much is being done in that direction.

Variation in Performance.—However, before proceeding further, some agreement must be reached on a basic understanding of the interrelation of these three elements. Leading to this understanding is the growing study of work decrement and delays that occur while performing work. Two very contradictory opinions are in circulation today. Wiberg refers to variation in performance or misrepresentation of the true work time in the following manner:

> Such misrepresentation generally occurs either as a variation from the standard method, or as a general slowing down of the movements, or as a combination of variation and slowing down. (3)

An investigation by Davis and Josselyn, however, led them to believe that:

> The operator uses the same work method and continues to work at the same rate of speed whenever the operation is performed, but introduces more and longer stoppages. (4)

It is the primary purpose of this presentation to add to the general knowledge of these two contrasting opinions.

Work-time Distributions.--Considerable investigation has been conducted at the Georgia Institute of Technology concerning work-time frequency distributions. The duration of time required for a person to perform a given task varies for each repetition of the task. An analysis of these variations using relative frequency of occurrence in certain time intervals has tended to refute an assumption generally accepted by work measurement personnel, namely that the distribution of work time variations assumes the form of the normal curve. Harold O. Davidson stated in 1952, "The assumption of normal distribution of relative production rates of industrial workers is operationally invalid." (5) The work since that time at Georgia Tech has substantiated Davidson's belief. At least statistically it has been proved that the assumption of normality for the distribution of relative production rates was incorrect in certain cases, namely manual, repetitive, worker controlled, short cycle, operations.

Inspection of the work at Georgia Tech reveals that it was based on small sample sizes. A second purpose of this presentation will be to attempt to substantiate those results with large sample sizes. These large samples are necessary in the proposed investigation of work decrement. If distributions of work times are obtained, the question of normality, and the conflicting opinions on work decrement, will be more brilliantly illumined.

CHAPTER II

LITERATURE SURVEY

Work Decrement and Fatigue.--Work decrement is a fairly recent term, its origin unknown, but its meaning is as old as work itself. Basically, it means the inability or lack of desire of a worker to perform his task at a constant rate of speed, or his inability to perform any work at all. It is a loose term, unscientific in nature, stemming from the early concept of fatigue.

Literature study reveals that industrial work decrement is a thing apart from pure physiological fatigue or objective fatigue, and it is also different from subjective fatigue based on psychological measurement. It has facets of both. Anderson (6) presented the idea that physical fatigue is not a necessary consideration in an industrial situation because improved industrial techniques and improved systems of worker selection have eliminated such consideration. This, coupled with the previous works of Muscio (7), ten years earlier, who said that fatigue could not be defined, caused many people to minimize the fatigue factor in industry.

Change in Concept.--However, among others, Mayo realized that a certain allowance still had to be made for what he called a reduced capacity for doing work. He defines this situation thusly:

> Work can be done only in a steady state; interruption comes in any ordinary industrial situation not from any partial exhaustion of fuel reserves but from some sort of "interference." This interference is of the nature of an external condition which

> carries as a consequence for certain individuals an actual organic disequilibrium which makes continuation of effort for such individuals impossible. (8)

This is in agreement with the definition of Cyrol. (9)

This interpretation caused a change in outlook in the field of work measurement. By 1947 Gomberg had said,

> A subtle but unexpressed change was taking place in the concept of fatigue allowance. The percentage added to the observed time was no longer understood as an actual rest period but was compensation for an implied slowdown loosely covered by the term fatigue. (10)

From this statement it might be construed that Gomberg agrees with the remarks of Wiberg in the previous chapter. In any event, Gomberg intimated that the work decrement factor is tied to speed or pace and not simply to stoppages or non-work time.

Mayo (11) stated that the only practical method of measuring work decrement was by measuring the output and quality of work done. C. S. Myers (12) agreed with him. Although much has been accomplished in the field of psychological fatigue measurement, this present study will use production observations and measurement in its analytical sections.

The Gilbreths stated in 1918, "'Time to rest when one needs it;' this is the first slogan of the campaign for eliminating the evils of over-fatigue." (13) From this early beginning, rest has been under investigation. Rest periods are today a common occurrence in American industry. During the Hawthorne experiments, Mayo noted that if rest pauses were removed production dropped and personal time increased. The variable, personal time appeared to be related to fatigue and was more easily measured. One of the most recent works in this field was reported in 1953 by Davis and Josselyn. (14)

Type of Work Analyzed.—They examined a manual, repetitive, worker-controlled operation for the relationship between personal delay and production. One of their findings has been previously reported in Chapter I. They hypothesized more exactly:

> That in manual, worker-controlled operations, the operator performs at his physiological limit and, when he can do so, seeks relief by controlling the ratio of non-working time to working time. (15)

Note the similarity between the type of operation analyzed by Davis and Josselyn and the previously mentioned general investigation at Georgia Tech.

Griffith, Kerr, and T. B. Mayo (16) state that curves of tiredness feeling were remarkably similar in manual, office, and supervisory employees. Hence a manual operation would appear to be a suitable type of work to investigate as it might then be possible to apply the derived knowledge from this type of study to a much larger area. Manual work is more readily measured than either of the other mentioned work categories.

A repetitive work situation should be chosen in this type of study because, "Fatigue packs its hardest punch in repetitive operations, particularly when only a few muscles are in constant play." (17) In addition, a worker-controlled operation would eliminate an enforced rhythm or pace. Brozek (18) maintains that an enforced slow rhythm increases boredom while an enforced rapid rhythm causes errors. If the worker is allowed to set his own rhythm and allowed some variety in performing the job, Bedford (19) maintains that the ideal work curve will be approached.

These three factors, modifying the type of work to be analyzed, outline the area of interest of this study.

In addition, the work studied should be short in cycle. This requirement is necessary in order to accomplish the two purposes of this presentation. Davis and Josselyn made their initial studies in work that required over fifteen minutes to manufacture a single unit of work. It is of value to know if their results are valid for short cycle jobs where a unit of work is produced in less than one minute. The work previously accomplished at Georgia Tech has required short cycle jobs, and in order to obtain the large sample size desired with the facilities available, this study must be made with cycles of the same general duration to assure valid relationships.

Work and Delay Relationships.--Davis and Josselyn investigated the relationship between working time and non-working time. They found that delays accounted for 29.7 per cent of all the time the worker was on the job. Of this 29.7 per cent, 23.7 per cent was delay of the personal or avoidable type. (20) They initially investigated:

Delay completely outside the operation cycle.

Delay within the operation cycle which consisted of slowing down the elements of the cycle.

Delay within the operation cycle which consisted of altering the elements of the cycle. (21)

Their findings led them to believe that all delay was of the first type. This delay occurring between cycles was termed external delay. However, they found certain delay of the non-working time classification within the operation cycles. This type of delay was not originally investigated. Together with their first type of delay classification, it is studied in this presentation. Their findings concerning the second and third types of delays are accepted at the beginning of this investigation. Only periods of non-working time will be analyzed and compared with working time, or time spent in production. The operator's speed or pace of performing the elements, and the alteration of elements while producing a unit of work, will be disregarded. Hereafter, the term delay will refer only to non-working time or working time that is non-productive by nature. These two classifications are explained more fully in Chapter V.

Bartlett agrees with Davis and Josselyn's findings and says concerning industrial situations, "The critical factor seems to be the change-over time or the time required to rest after one operation before the next is started." (22) A search of the literature reveals no reference to consideration that this critical factor may occur within the cycle or during the period when the worker is actually manufacturing one unit.

Length of Observation Period.--E. Mayo reported,

> In work of which the main feature is repetition rather than effort, boredom and monotony are the factors to be taken into account rather than fatigue (physical) and here the action of rest pauses probably depends on change from the main occupation rather than on complete cessation of work. (23)

For this reason it was desirable to get as long a period as possible to observe one operator with the facilities at hand without encountering an authorized rest stop, and to record all changes from the main occupation as delays.

Other Secondary Factors.--The type of operation, frequency of operation, pace or speed required, rhythm, physiological requirements, and type of delay have been briefly discussed heretofore. Other secondary factors will be discussed during the narration of the steps necessary in the formation of a procedure for this study.

CHAPTER III

PREVIOUS RESEARCH AT GEORGIA INSTITUTE OF TECHNOLOGY

During the past five years an investigation of work-time patterns has taken place at the Georgia Institute of Technology, under the direction of Doctors Robert N. Lehrer and Joseph J. Moder. The results of some of this research were published by them (24), and much of the individual research is found in theses of Lind (25), Taft (26), McLeod (27), Friedman (28), and Summers (29). The nature of their work was to attempt to analyze statistically the characteristics of a worker's performance pattern, and an attempt to find a model for the work-time distribution of a manual, worker-controlled, repetitive operation. The operation cycle was short.

Lind used conventional stop-watch timing and a sampling technique to obtain his work times. He found the performance times for most operators to be statistically unstable and was unable to establish a theoretical work curve. Taft used micromotion techniques of timing and a sampling technique to obtain his work times. He then removed all film samples having gross variations from the standard method, and eliminated the first and last elements of each cycle because of their variation. He found the distribution of these "modified cycle times" tended to be positively skewed and that they could be approximated by the Log-Normal Curve. McLeod took Taft's data and attempted to remove certain assignable causes of variation in order to see if their removal would make the cycle times more stable. He found that this removal of conventionally classified variables did not significantly affect the stability of the cycles. At this point in the research, "pure" work cycles, with all variables discernable under exhaustive study having been removed, did not become stable.

Friedman chose to work with data from the few operators in both Lind's and Taft's data who were stable. He found that the distributions of their work times differed from the Normal Distribution, were positively skewed and could be best approximated by the Pearson Type III Curve.

Summers summed up the limitations of the research at that point as follows:

1. The experiment covered only one operation in one plant.
2. The data represented a limited number of operators.
3. The operators seemed to be highly motivated.
4. The cycle time sample sizes for the individual distributions ranged from 125 to 150 in Study A (Lind), and were considerably smaller in Studies B (Taft) and C (McLeod).
5. A limited number of variables were classified in Study C, and these were visually detectable.
6. The measure of stability used in this study ("variance between periods")...is not necessarily the best ultimate measure of cycle time stability. (30)

In his research he found that cycle time stability has no direct relationship to mean time, skewness, or peakedness of the distribution, but that it does have a relation to the dispersion of the distributions. He found little relationship between stability and the goodness of fit for Normal, Log-Normal, and Pearson Type III Curves. He recommended that further studies be made of similar operations using much larger sample sizes. (31)

In conjunction with the delay aspects of this study, this recommendation has been carried into effect in order to obtain distribution curves based on larger sample sizes. These curves can then be compared with the results of this previous research.

CHAPTER IV

OBJECTIVES

Summers concluded:

> For an operation of the type studied, the theoretical work-time distribution is positively skewed. Thirty-eight values of g_1 have an average of about 1.0 and a standard deviation of approximately 0.55 for the individual values. The peakedness of the distribution is slightly greater than that of a Normal Curve, the "a" values having a mean of about 0.76 and a standard deviation of about 0.05 for the individual values. The standard deviations for both skewness and peakedness values decreased markedly when cycles containing variables were removed from the data. (32)

The first objective of this study was to determine if there is any similarity between Summers' conclusions based on small samples, and measurements of skewness and peakedness based on large samples with all variables remaining within the work cycles, or based on the samples remaining after all cycles containing internal delays have been removed.

The second objective of this study was to determine if the mean, standard deviation, skewness, and peakedness decrease when cycles containing internal delays have been subtracted out, and the remaining cycle times are analyzed.

The third objective of this study was to determine if the mean and variance of the distribution of the work cycles including all variables are significantly different from the mean and variance of the distribution of the work cycles remaining after all cycle times containing internal delays have been subtracted out.

For partial proof of the hypothesis of Davis and Josselyn, delay outside of or between cycles must be significantly greater than internal delay. Proof of this was the fourth objective of this study.

In addition, variance of the distribution of the work cycles remaining after all cycle times containing internal delays have been subtracted out, should not differ significantly from observation period to observation period for each operator. This was the fifth objective of this study.

As an adjunct to these five objectives, four distributions were obtained for each observation period for each operator.

> Frequency distribution of all cycle times. (Raw Cycle Distributions)
>
> Frequency distribution of cycle times remaining after all cycles containing internal delays were removed. (Modified Cycle Distributions)
>
> Frequency distribution of external delay times.
>
> Frequency distribution of internal delay times.

Histograms of these distributions are presented for comparison in Appendix C. Furthermore, analyses of variance for distribution means and standard deviations were made. An analysis of variance of production accomplished was also made for comparison to the analyses made on the two distribution parameters.

Davis and Josselyn noted a close relationship between the amount of personal time and production and that there was no apparent change in the operation time. (33) This study should help substantiate or deflate the value of their conclusions.

CHAPTER V

PROCEDURE

Operation Chosen.--In surveying possible jobs for analysis that would meet the requirements set forth in Chapter II, it became apparent that an industrial work situation was more desirable than a laboratory or simulated task. R. A. Spaeth has previously expressed doubts as to the validity of fatigue or delay studies done wholly within the laboratory. (34) It also is the policy of the department for whom this study was made to have the analysis done in industrial situations wherever possible. An inspection of various industries who would cooperate in the study revealed only one company which had operations short enough to meet the requirements desired. This company was Scripto, Inc., 423 Houston St., N. E., Atlanta, Georgia.

The operation decided upon was one of the assembly steps in the fabrication of a ball point pen. The over all assembly consisted of three steps:

> Assembly of pen cap, cap sleeve, pocket clip, and actuating button.
>
> Assembly of alignment sleeve, plunger, latch spring, and cap previously assembled.
>
> Assembly of cap assembly, barrel, writing unit, and compressing unit.

The final assembly was followed by test and inspection.

The second assembly step was chosen as the specific operation to be analyzed. Supply of parts was not as variable in this assembly as in the first step, nor were inspections as frequent for possible malfunction as in the third step. Careful observation also revealed that the operator in this second step was not under as frequent production pressures as in the other two assemblies, for it was the longest of the three stages in assembling the pen; and various other operators manned extra facilities for this second assembly step as they built up a backlog of parts in their own assembly area. The operators analyzed worked constantly at this one assembly.

Operation Description.--A brief description of the elements involved in the task is given below. A sample therblig analysis of the operation may be found in Appendix A.

Left Hand

1. Move to alignment sleeve, grasp, move to staking fixture and drop in place.
2. Move to plunger, grasp, move to assembly area in front of operator to meet right hand.
3. Assemble plunger and latch spring and transfer assembly to right hand.

Right Hand

1. Remove finished assembly from staking fixture, move to aside position and drop.
2. Move to latch spring, grasp, move to assembly area in front of operator to meet left hand.
3. Assemble latch spring and plunger and receive assembly from left hand.

Left Hand	Right Hand
4. Move to cap assembly, grasp, move to staking fixture and assemble in fixture.	4. Move plunger assembly to staking fixture and assemble in fixture. Wait for staking to be completed.

5. Staking fixture operated by foot pressure.

Operation End Points.--Further observation revealed that most operators would stop at the end of the first element of the right hand, if they wished to rest, secure new supplies, clean their staking fixture, etc. As this was the natural end point of the cycle, and not the staking position itself, the transition point between elements 1 and 2 for the right hand was considered the end point of one operation. Specifically, all cycle times were recorded at the point where the finished assembly was released by the operator. Furthermore, as delays appeared frequently at this transition point, the period of external delays commenced at this point. If no delay occurred, then naturally this point was the beginning point of the next cycle. If a delay between cycles occurred, then it ended and the next cycle began when the hand finished all delay or extraneous movement and commenced a definite and direct movement in the direction of the latch spring supply area. Internal delay times are discussed at length later in this chapter.

Location of Assembly Items.--To assist the reader in locating the positions of the various parts and operating areas, a layout diagram can be found in Appendix A.

Operators and Working Conditions.--The operators to be analyzed in this job were female, Negro personnel, working in groups of four or five to an assembly line. The wages received for their work were generally higher than similar labor in similar jobs in the Atlanta area. Motivation was judged to be high, although no incentives were paid. A production goal was set and there was considerable competition between the four or five groups working on these particular assembly lines to see which group could exceed the production goal for the shift by the highest margin. Extra compensation was not received for success in this competition. William Muse, a graduate student at Georgia Tech, is currently evaluating this motivation as part of his thesis study. The operators were allowed to shift positions and perform the three basic assemblies as the senior worker in each group would allow. In this manner, assemblies 1 and 3 could "help out" on the assembly studied by a shift in personnel placement. Two shifts were working each day on the following hours:

1st Shift		2nd Shift
7:00 A.M.	Begins	3:20 P.M.
9:45--9:50 A.M.	Rest Break	
12:00--12:20 P.M.	Lunch	6:10--6:30 P.M.
1:45--1:50 P.M.	Rest Break	9:00--9:10 P.M.
3:20 P.M.	Ends	11:40 P.M.

Total working time per shift was seven hours and fifty minutes. It should be noted that production rarely commenced at exact times. The work area was clean with good lighting and fair ventilation, all assembly lines being located in one large room. Some crowding between lines was observed, but not sufficient to hinder the worker's movement at the work place. Conversation and work stoppages could occur at the discretion of the employee. One white male was foreman over all assembly lines.

Choice of Observation Period.--Analysis of any work on the first shift was eliminated by consideration of this writer's personal employment schedule. To obtain a sufficiently large sample of observed cycles without authorized interruptions, it became essential to choose a period of two hours continuous work without company authorized breaks or rest periods. Two such periods existed during the second shift. Due to the possibility of various assembly lines slackening their pace when their production goal was reached or neared, it became necessary to use the 3:20--6:10 P.M. period in these observations. As it was desirable to analyze various operators at similar working hours, and there was only one convenient period per day to observe one operator, various days toward the center of the week were used in order to minimize any "week-end" effect.

Selection of Operators.--The operators were not selected by psychological test, or dexterity test. Of the approximate 20 operators qualified for this job, about seven or eight expressed a liking for the particular assembly under consideration. These operators performed this operation continuously, in preference to rotating among the shorter cycles of their particular production line. Of these eight, three were chosen as being of similar experience and background by the foreman in charge. It is also noted that these operators were selected from assembly lines with the better production records. Rothe analyzed the production records of operators of equal experience on jobs where the workers control their own pace and found that the range of performance was roughly 1.73 to 1. (35) This indicated that a two to one difference in production levels should not be viewed with alarm, when operators are selected in this manner.

In any industrial analysis, especially where worker performance is under evaluation, it is preferable to interfere as little as possible with the worker. To give tests to select scientifically the operators under analysis in this study would have entailed interruption of the worker's regular routine, and involved possible loss in production for their production line. Furthermore, the operators were of fairly low educational level and possible validity of any of the more refined personnel ranking techniques, except the simplest dexterity tests, was doubtful. Therefore, the foreman's selection was used to choose the operators to be observed.

Of the three operators chosen, the one with the best mean production time was observed a second time in order to determine any individual variation in level of performance.

<u>Preliminary Investigation of Cycle Time</u>.—In order to familiarize the observer with the cycle to be analyzed and to provide a laboratory film for practice with the timing device to be used, a preliminary investigation of the operation was made, using micromotion procedures. One hundred feet of film were exposed at the rate of 1000 frames per minute. This film was analyzed and the following results were obtained for an experienced operator, not one of those analyzed in this study. These

results are not part of the analysis and the results are presented for the reader's familiarization only.

Forty-eight cycles were performed, three of which had external delays of sufficient length to remove them from consideration at this exploratory stage.

Mean cycle time	.088 minutes
Median	.084 minutes
Mode	.076 minutes

Eliminating all of the simplest visual variables such as fumbles and staking fixture difficulties, thirty-nine cycles remained having a mean of .084 minutes. Still further removal of cycles that appeared extra long for no directly visual cause left twenty-eight cycles remaining with a mean of .078 minutes. It was noted that these extra long cycles possibly occurred because of extra time being consumed in Element 3, as described in the Brief Job Description. All fumbles except for staking fixture difficulties appeared to be inherent in the job as parts fitted with small tolerances and locations necessarily had to be exact. Although this study had too few cycles in it to be of great value, the cycle time and hourly production could be approximated and insight was gained in the types of internal delays that might occur.

Classification of Delays.--The beginning and end points of external delays have been discussed previously. They included all time between the end motion completing one unit of production and the beginning motion for the next unit of production. This period was spent in a variety of ways, including rest, motions of a personal nature, and work that was necessary in the over all job performance such as reaching for new supplies, straightening the work area, putting a pile of completed units within reach of the next worker in the assembly line, etc. These extraneous motions of the worker, even though they accomplished some useful work, were called delays because the worker controlled their occurrence and the pattern of her departure from the standard task was important to this study. External delays could be classified as:

1. Operator controlled delays involving stoppages or personal motions and actions having no direct relation to the operation.
2. Operator controlled delays involving productive work or motions having some direct relation to the operation.
3. Authorized delays over which the worker had no control such as interruption by foreman, failure of staking fixture, etc.

This third classification was eliminated from the study as the field of interest lies with delays or interruptions that the operator can control.

Internal delays were more difficult to define and detect. If the hypothesis of Davis and Josselyn is true, the worker should not change her basic motion pattern. Preliminary study showed certain fumbles were inherent in the operation. These fumbles resulted in repetition of a basic motion pattern. Therefore, these motions were not classified as true delays. Extraneous actions or a sudden change in motion purpose, however, had to be classified as delays if the criteria of Davis and Josselyn were to be followed. This was a basic assumption of this study.

Internal delays could be classified as follows:

4. Worker controlled delays involving stoppages or personal motions and actions having no direct relation to the operation.
5. Worker controlled delays involving productive work or motions differing from the basic motion pattern, or repetitions thereof, having some direct relation to the operation.
6. Authorized delays over which the operator had no control of the same general features as class 3 delays.

Classifications 4 and 5 all fall within the general definition of delay given in Chapter II, except that the term nonproductive work used in that chapter was expanded to include productive work that does not occur in the basic motion patterns of producing cap assemblies for ball point pens. The 6th classification was eliminated from the study.

The beginning point of all internal delays was the point at which the observer first detected a significant departure from the basic motion pattern. The end point of such delays was the point at which the observer first detected a resumption of a definite and direct movement that was a part of the next logical motion in the cycle. Detection of these points involved a judgment process and involved certain practice runs of considerable duration prior to the actual observations for experimental data.

<u>The Observer</u>.—All observations were taken by the writer in order to eliminate variation between observers. The observer was tested for stop

watch reading accuracy less than a month before the data was gathered, and ranked second in a group of twelve men practiced in work measurement. Although this test did not require physical reaction to the stimulus, it is indicative of the visual and perceptive powers of the observer. The observer insured sufficient practice was obtained in observation timing and classification to eliminate any further learning curve process in the actual experimentation area of this study. As the timing device used was of radical design, not previously used in work measurement, the observer followed its development from its inception and felt qualified in its use within the degree of accuracy of the analysis. Test runs revealed that reaction time inaccuracies would creep into the study if all six aforementioned delay classifications were used. For this reason, delays were simply classified into two types:

External -- delay between cycles.

Internal -- delay within cycles.

All class 3 and 6 delays were eliminated, as previously mentioned. In addition, preliminary observation revealed that there were too few delays of the class 1, 2, 4 or 5 variety to treat properly in a statistical sense, even if they had been classified as such in the data gathering process.

CHAPTER VI

INSTRUMENTATION

Sample Sizes and Method of Timing.—One of the most serious drawbacks to previous research at Georgia Tech in the particular area of work measurement under discussion was the size of the samples from which statistical inferences were drawn. Conventional time study using stop-watch procedures was found to have certain inherent variables and inaccuracies that affected the study. Cycle times could only be recorded to the nearest hundredth of a minute, certainly an undesirable feature in the analysis of short cycle work. Micromotion technique increased this accuracy to one thousandth of a minute, but at the cost of increasing the expense of the analysis in material and in the time spent in analyzing the film. This disadvantage limited the results of any experimentation to conclusions and additional hypothesis based on samples of less than 150 cycles analyzed per operator.

One of the first requirements, therefore, for further exploration in the field of frequency distributions of work times was to increase the sample size per operator to 1000 observations or more. Using film analysis techniques would have cost about $120 per operator for the operation chosen, or around $500 for the data gathering necessary for this presentation. A kymograph was then considered as a cheaper method of recording data, but the length of analysis time was equivalent to that of micromotion analysis.

Timing Instrumentation Desired.--What was needed was a method of observing the points to be recorded and to have the time between points printed out in the order of its occurrence, or to have this data punched directly into punched cards as it occurred.

Without the knowledge or facilities to design and perfect this device, it became necessary to inspect the open market for such a device. Of all instrument manufacturing agencies investigated, the Clary Corporation, manufacturers of business machines, electronic and automatic conrols, and aircraft and missile components, had the closest instrument to the desired device. This was the Clary Time Data Printer, which printed time separately or cumulatively to the nearest hundredth of a minute.

Consultation with Mr. J. N. Smith of that organization revealed that it might be possible to add the desired features to their Time Data Printer and achieve a Milliminute Timer. The additional features of this Timer were:

A pulse generator to set up a timing pulse of exactly 1/1000 of a minute.

An accumulator to count these pulses between operation of the printing switch.

A print-out mechanism to provide a visual record of accumulated time. (Clary Time Data Printer)

A reset device to reset instantaneously the accumulator to zero whenever the printing switch was operated.

A series of codifying keys to classify the data as it was printed out. (Either numerically or alphabetically)

Purchase of Milliminute Timer.--Designers for the Clary Corporation designed such a device for less than two thousand dollars and it was purchased by the School of Industrial Engineering at the Georgia Institute of Technology for use in this study and further investigations in the field of work measurement. Without the financial aid from the School of Industrial Engineering, this particular study would have been impossible, for the analysis time required using any other well known method of work cycle timing would have been greater than a single individual could accomplish in the time the writer had available.

This equipment was ordered in December 1955, and was delivered, ready to operate, in the latter part of March 1956. The lengthy construction time occurred as a result of an entire change of design. Electromagnetic relays were found to be incapable of the accuracy desired, and the redesigned equipment made much more use of electronic circuits and vacuum tube principles.

Component Parts of Milliminute Timer.--The instrument consisted of two units. The read-out or printing section was a Clary Time Data Printer modified with two columns of coding keys 0-9, so that input data could be classified from 1 to 99. A read-out micro switch was located on the printer. This activated the entire device.

The second unit contained a pulse generator generating 16.6 cycles per second, a counter unit or accumulator, four buffers to increase the current outputs from the counter to operate decoding relays and readout relays, four relays connected in matrix form to decode times less than 1/100 of a minute, and four more relays to operate the conventional read-out inputs to the first unit. The read-out switch merely opened a read-out gate device to allow the flow of accumulated times to the printing unit. At the same instant the decoded times from the matrix relays were allowed to flow and print times from 0.000 to 0.009 minutes independently of the standard read-out gates which detected all times from 0.00 to 99.99 minutes. A block diagram, simplified operating instructions, and a more detailed description of the operation of component parts may be found in Appendix B.

Accuracy.—The milliminute timer records time to the nearest one thousandth of a minute. However, because of the time necessary to print out the data, events less than 0.006 minutes in duration cannot be timed. No events less than 0.01 minutes had to be recorded in this study. The observation reaction time required to actuate the print out switch produces more error in this study than the instrument itself. The variation in reaction time is in the neighborhood of two thousandths of a minute. Frequency distributions and records of the data obtained were recorded for analysis purposes in hundredths of a minute from the data which was recorded in thousandths.

CHAPTER VII

ANALYSIS

Tabulation.--The data was tabulated into six frequency distributions for each of the four operators, A, A', B, and C, for each hour of their two hour observation periods. These distributions were:

> Distributions of raw cycle time frequencies
>
> Distributions of cycle time frequencies remaining when all cycle times containing internal delays had been removed, hereafter called the Modified cycle time distributions
>
> Distributions of external delay time frequencies
>
> Distributions of internal delay time frequencies
>
> Distributions of the cycle time frequencies which contained internal delays
>
> Distributions of these latter cycle time frequencies after the actual internal delay times had been removed from the individual cycles

These latter two types of distributions were not analyzed in this study, as they were not an integral part of the area under investigation.

These first four distributions were combined to get a distribution for all operators for their two hour work period. They were further combined to get the grand distributions for all operators, and both of Operator A's two hour periods were combined as this was the operator who was measured on separate occasions. All mathematical analysis was then performed using the distributions obtained. Tables of the basic distributions may be found in Appendix C, Tables 11-24.

Moments.--The following parameters were obtained for all distributions analyzed:

Mean -- $\overline{X}$

Standard Deviation -- s

Coefficient of variation -- va

Measure of Skewness -- g_1

Measure of Peakedness -- g_2

These were computed by solving for the moments according to the following sets of equations:

F -- frequency occurring in any class interval

A -- arbitrarily chosen class mark approximating the mean

d -- number of the class interval, ordered on either side of the class interval containing A

c -- width of class interval

N -- total number of observations in the period

m_2-- 2nd central moment

m_3-- 3rd central moment

m_4-- 4th central moment

V_1-- 1st basic moment -- sum of $\frac{dF}{N}$

V_2-- 2nd basic moment -- sum of $\frac{d^2F}{N}$

V_3-- 3rd basic moment -- sum of $\frac{d^3F}{N}$

V_4-- 4th basic moment -- sum of $\frac{d^4F}{N}$

$$\overline{X} = A + V_1c$$

$$m_2 = V_2 - (V_1)^2$$

$$s = c(m_2)^{\frac{1}{2}}$$

$$va = \frac{s}{\overline{X}} \times 100$$

$$m_3 = V_3 - 3V_2V_1 + 2(V_1)^3$$

$$g_1 = \frac{m_3}{(s)^3}$$

$$m_4 = V_4 - 4V_3V_1 + 6V_2(V_1)^2 - 3(V_1)^4$$

$$g_1 = \frac{m_4}{(m_2)^2}$$

These measurements were calculated for the thirty-eight distributions analyzed. The necessary checks for the mathematics involved were made as the smaller distributions were combined to get the over all distributions. Tables of these measurements may be found in Chapter VIII, Tables 1-3.

Confidence Intervals and Tests.--Confidence intervals for grand distribution means and standard deviations for all operators were established at a 95 per cent confidence level according to the following formula:

Mean $$\overline{X} - Z\frac{s}{(N)^{\frac{1}{2}}} < m < \overline{X} + Z\frac{s}{(N)^{\frac{1}{2}}}$$

where $Z = 1.96$ and m is the population mean

Standard Deviation $$s - Z\frac{s}{(2N)^{\frac{1}{2}}} < \sigma < s + Z\frac{s}{(2N)^{\frac{1}{2}}}$$

These confidence intervals are compiled in Chapter VIII, Table 4.

The means of the raw cycle times, modified cycle times, external delays and internal delays of the combined periods for individual operators were then tested against the means of the grand distributions for all operators at the 0.05 level of significance using the following formula:

$$Z = \frac{\bar{X} - m}{\frac{s}{(N)^{\frac{1}{2}}}}$$

where m = 0.08205 for raw cycles, 0.08062 for modified cycles, 0.1543 for external delays, and 0.03462 for internal delays, and Z is the normal standard deviate. The significance of these means can be found in Chapter VIII, Table 5.

As these results did not necessarily indicate the significance of the performance of the operators, it then became necessary to test each operator's mean against every other operator's mean for raw cycles, modified cycles, external delays, and internal delays. This was done for the combined periods, using the formula:

$$Z = \frac{\bar{X}_1 - \bar{X}_2}{\left(\frac{(s_1)^2}{N_1} + \frac{(s_2)^2}{N_2}\right)^{\frac{1}{2}}}$$

Z is the normal standard deviate.

This formula is based on the assumption of normality for large sample sizes. The results of this test may be found in Chapter VIII, Table 6.

As there was some doubt as to the rigor of this test, a similar mathematical analysis was performed using the Multiple Range technique lately developed by D. B. Duncan. (36). The use of this technique showed identical results at the 0.05 level of significance for differences between operators.

The standard deviations of the raw cycle times and modified cycle times of the combined periods for individual operators were then tested against the standard deviation of the grand distributions for all operators at the 0.05 level of significance by establishing confidence limits for each operator according to the formula previously presented. These confidence limits are listed in Chapter VIII, Table 7.

This, also, did not necessarily give significance of performance, and it became necessary to test each operator's standard deviation against every other operator's standard deviation for raw cycles, modified cycles, external delays and internal delays. This was done by using the simple F test:

$$F = \frac{(s_1)^2}{(s_2)^2}$$

F is determined by the N_1 and the N_2 of the operators being compared. As all N values for raw cycle and modified cycle distributions were over one thousand, the tables were entered with that value for N_1 and N_2. For the smaller size delay distributions, conventional entry was made in F tables. These results may be found in Chapter VIII, Table 8.

Tests for Normality.--The parameters g_1 and g_2 were tested for normality for purposes of comparison with previous experimentation done at Georgia Tech. As the raw and modified cycle times were based on large samples, a simple test could be made. This was done by using the formulas:

$$\text{Skewness} \qquad Z = g_1 \left(\frac{N}{6}\right)^{\frac{1}{2}}$$

$$\text{Peakedness} \qquad Z = g_2 \left(\frac{N}{24}\right)^{\frac{1}{2}}$$

Z is the normal standard deviate.

The delay parameters were derived from such small samples that the above technique no longer held true and they had to be compared with tables for g_1 and g_2 previously presented by Bennett and Franklin. (37) Even these tables did not include sufficient values for some of the small sample sizes involved. This is noted in Chapter VIII, Table 9, where the values of Z are recorded.

Analysis of Variance.--An analysis of variance was made on the distribution means, distribution standard deviations, and production for each hour of every operator, for the raw and modified cycle times. The data for the compova table appeared as follows:

Source of Variation, or Factor	Super-script	Sub-script	Model No.	Symbol	No. of Levels
Type of Cycle (Raw, Modified)	C	i	I	A_i^C	2
Periods (1, 2)	P	j	I	A_j^P	2
Operators (A, A', B, C)	O	k	I	A_k^O	4

The Model Equation was:

$$X_{ijk} = m + A_i^C + A_j^P + A_k^O + A_{ij}^{CP} + A_{ik}^{CO} + A_{jk}^{PO} + A_{ijk}^{CPO}$$

The latter term was used as the error term. As all sources of variation were Model I, the technique developed by Brownlee (38) could be used in this instance to obtain the mean squares. The results of this analysis are shown in Chapter VIII, Table 10.

CHAPTER VIII

RESULTS

Production.--The production per operator per hour ranged from 647 items to 728. This gave a ratio of best hourly production to poorest hourly production of 1.125 to 1. In a similar manner, the ratios for combined periods were 1.115 to 1. These production ratios tend to indicate for this particular set of observations that the operators chosen were generally similar. This was to be expected as they were not chosen randomly.

A total of 5,492 items was produced, distributed among the operators with distribution parameters as shown in Tables 1 and 2. The production rankings were:

	Op. A	Op. A'	Op. B	Op. C
		Raw Cycles		
Period 1	2	1	3	4
Period 2	3	1	2	4
Combined Periods	3	1	2	4
		Modified Cycles		
Period 1	2	1	3	4
Period 2	3	1	2	4
Combined Periods	2	1	3	4

(Lowest ranking equals highest production.)

Table 1. Parameters for Distribution of Raw Cycle Times

	1st Hour				2nd Hour			
	A	A'	B	C	A	A'	B	C
Production N	693	718	686	647	676	728	694	650
Mean $\bar{X}$	.07860	.08181	.08141	.09009	.08016	.07938	.08118	.08608
Standard Deviation S	.01668	.01200	.01892	.01576	.01514	.01337	.01844	.01566
Coefficient of Variation va.	21.2%	14.7%	23.2%	17.5%	18.9%	16.8%	22.7%	18.2%
Measure of Skew. g_1	2.9107	2.8088	1.5515	1.8880	2.9998	2.1664	2.2449	1.3269
Measure of Peakedness g_2	17.2529	14.9670	3.8612	8.3734	17.9595	10.2303	9.9947	3.4272

	Combined Periods				All Periods Operator A, A'	All Periods All Operators
	A	A'	B	C		
Production N	1369	1446	1380	1297	2815	5492
Mean $\bar{X}$	.07950	.07978	.08130	.08808	.07964	.08205
Standard Deviation S	.01595	.01340	.01868	.01584	.01470	.01641
Coefficient of Variation va.	20.1%	16.8%	23.0%	18.0%	18.5%	20.0%
Measure of Skew. g_1	2.9819	2.1285	1.8900	1.5735	2.6642	2.0416
Measure of Peakedness g_2	16.8131	9.9862	6.7873	5.8866	15.4736	9.0647

Table 2. Parameters for Distribution of Modified Cycle Times

	1st Hour				2nd Hour			
	A	A'	B	C	A	A'	B	C
No. of Cycles N	676	705	656	631	662	717	672	628
Mean $\bar{X}$	.07740	.07922	.07950	.08878	.07893	.07852	.07879	.08478
Standard Deviation S	.01242	.01097	.01560	.01281	.01125	.01109	.01417	.01348
Coefficient of Variation va.	16.1%	13.9%	19.6%	14.4%	14.3%	14.1%	18.0%	15.9%
Measure of Skew. g_1	.6644	.7474	1.0385	.5181	.5234	.8577	.6055	.7421
Measure of Peakedness g_2	.9933	1.9404	2.3274	.9261	.5821	1.5366	.6630	1.2408

	Combined Periods				All Periods	All Periods
	A	A'	B	C	Operator A, A'	All Operators
No. of Cycles N	1338	1422	1328	1259	2760	5347
Mean $\bar{X}$	.07815	.07868	.07914	.08678	.07852	.08062
Standard Deviation S	.01188	.01104	.01489	.01330	.01146	.01328
Coefficient of Variation va.	15.2%	14.0%	18.8%	15.3%	14.6%	16.5%
Measure of Skew. g_1	.5845	.8019	.8596	.5949	.6783	.7305
Measure of Peakedness g_2	.8199	1.7214	1.7158	.9385	1.2423	1.3504

Thus it may be seen that production rankings per hour for individual operators were not affected by removal of cycles containing internal delays, but that removal of such cycles did affect the rankings for combined periods.

This production ranking indicates that Operator A on the occasion of her replicate test performed better than the other operators observed, and that Operator C was the least productive of the workers observed. The mean production for all operators was 686.5 items per hour with a standard deviation of 27.0 items. The production rates of Operator A and B lay close to the mean, while Operator A' exceeded the mean substantially during each hour, and Operator C achieved considerably less than the mean in both hours.

Number of Delays.--Delays were only calculated for combined periods of each operator because the sample size in each hour was too small for arriving at statistically valid relationships. The ratio of the largest number of delays to the smallest number of delays for combined periods was 1.794 to 1 for external delays and 2.166 to 1 for internal delays. These ratios were not similar to the production ratios for combined periods.

A total of 336 delays were observed, distributed among the operators with distribution parameters as shown in Table 3. The delay rankings for combined Periods were:

Table 3. Parameters for Distribution of Delay Times

	External Delays (Combined Periods)					Internal Delays (Combined Periods)				
	A	A'	B	C	All Opers.	A	A'	B	C	All Opers.
No. of Delays N	47	34	49	61	191	31	24	52	38	145
Mean $\bar{X}$	.1807	.1503	.1830	.1130	.1543	.06064	.02625	.02673	.02947	.03462
Standard Deviation S	.09817	.08151	.06350	.07287	.08493	.04056	.00696	.01410	.01146	.02552
Coefficient of Variation va.	54.3%	54.2%	34.7%	64.5%	55.0%	66.9%	26.5%	52.7%	38.9%	73.7%
Measure of Skewness g_1	.4818	1.2130	.1588	1.3056	.7174	.7309	-.7300	.8792	.8375	2.4177
Measure of Peakedness g_2	-.9635	.7025	-.5433	1.6054	-.2015	-.8522	-.7379	.4103	-.0813	6.2443

	Op. A	Op. A'	Op. B	Op. C
		External Delays		
Combined Periods	2	1	3	4
		Internal Delays		
Combined Periods	2	1	4	3

(Lowest ranking equals least number of delays.)

Only in the case of Op. A' is there any direct relationship between these rankings of both types of delays and production ranking. However, the rankings of External Delays do relate directly to the rankings of production if cycles with no internal delays are removed.

It should be noted that Operator A took fewer rest periods than Operators B or C in both initial observation periods (A) and replicate periods (A'). The average number of delays per hour was 42 with a standard deviation of 9.5 delays. The number of delays of Operator A' who had the best production rate was less than the mean number of delays for all operators by a considerable amount in both hours.

Means of Raw and Modified Cycle Times.--The mean times in minutes for the production of one item, per operator, ranged from 0.07860 to 0.09009 for raw cycle times and from 0.07740 to 0.08878 for modified cycle times. This gave a ratio of largest average to smallest average of 1.146 to 1 for raw cycles and 1.147 to 1 for modified cycles. In a similar manner, the ratios for combined periods were 1.121 for raw cycles and 1.114 for modified cycles.

The rankings for the means as derived from Tables 1 and 2 were as follows:

	Op. A	Op. A'	Op. B	Op. C
	Raw Cycle Time Distributions			
Period 1	1	3	2	4
Period 2	2	1	3	4
Combined Periods	1	2	3	4
	Modified Cycle Time Distributions			
Period 1	1	2	3	4
Period 2	3	1	2	4
Combined Periods	1	2	3	4

(Lowest ranking equals smallest mean cycle time.)

Except for Operator C, these rankings for any one operator do not wholly agree with the production achieved or with the ranking of the number of delays. Hence it does not necessarily follow in this study that the operator with smallest mean time for producing an item will achieve the most outstanding production record.

The grand distribution means for all operators, as taken from Table 4, were 0.08205 for raw cycles times and 0.08062 for modified cycle times. The means for distributions of individual operators' combined period were tested for significance of difference from these grand means and all differed significantly except the raw cycle mean for Operator B. The levels of significance are shown in Table 5.

The distribution means for combined periods of individual operators were tested against each other for significant difference. The levels of significance are shown in Table 6. The elimination of cycles containing internal delays from the distributions tended to bring the averages of

Table 4. 95% Confidence Limits for Grand Distribution Means and Standard Deviations for all Operators

	Means	Standard Deviations
Raw Cycles	$.081616 < .08205 < .082484$ N = 5492	$.016104 < .01641 < .016716$ N = 5492
Modified Cycles	$.080264 < .08062 < .080976$ N = 5347	$.013027 < .01328 < .013533$ N = 5347
External Delays	$.14223 < .15427 < .16631$ N = 191	$.07642 < .08493 < .09344$ N = 191
Internal Delays	$.03047 < .03462 < .03877$ N = 145	$.02258 < .02552 < .02846$ N = 145

Table 5. Significance of Deviation of Distribution Means from the Mean of the Grand Distributions

Operator	Mean	N	Z Value	Level of Significance	Mean	N	Z Value	Level of Significance
Raw Cycle Distribution - population mean = .08205					Modified Cycle Distribution - population mean = .08062			
Op. A	.07950	1369	5.92	.00001	.07815	1338	7.61	.00001
Op. A'	.07978	1446	6.43	.00001	.07868	1422	6.62	.00001
Op. B	.08130	1380	1.49	.10	.07914	1328	3.63	.001
Op. C	.08808	1297	13.70	.00001	.08678	1259	16.44	.00001
External Delay Distribution - population mean = .1543					Internal Delay Distribution - population mean = .03462			
Op. A	.1807	47	1.84	.05	.06064	31	4.14	.0001
Op. A'	.1503	34	.286	.20	.02625	23	5.77	.00001
Op. B	.1830	49	3.16	.002	.02673	52	4.03	.0001
Op. C	.1130	61	4.42	.00001	.02947	38	2.77	.01

Table 6. Significance of Differences Between Distribution Means

Operator	Mean	N	Z Value	Level of Significance	Mean	N	Z Value	Level of Significance
	Raw Cycle Distributions				Modified Cycle Distributions			
Op. A vs Op. A	.07950 .07978	1369 1446	.5026	.20	.07815 .07868	1338 1422	1.076	.20
Op. A vs Op. B	.07950 .08130	1369 1380	2.719	.01	.07815 .07914	1338 1328	1.897	.05
Op. A vs Op. C	.07950 .08808	1369 1297	13.928	.00001	.07815 .08678	1338 1259	17.400	.00001
Op. A' vs Op. B	.07978 .08130	1446 1380	2.475	.02	.07868 .07914	1422 1328	.9145	.20
Op. A' vs Op. C	.07978 .08808	1446 1297	14.716	.00001	.07868 .08678	1422 1259	17.017	.00001
Op. B vs Op. C	.08130 .08808	1380 1297	10.1497	.00001	.07914 .08678	1328 1259	13.791	.00001
	External Delay Distributions				Internal Delay Distributions			
Op. A vs Op. A'	.1807 .1503	47 34	1.52	.10	.06064 .02625	31 24	4.63	.00001
Op. A vs Op. B	.1807 .1830	47 49	.136	.20	.06064 .02673	31 52	4.49	.00001
Op. A vs Op. C	.1807 .1130	47 61	3.96	.0001	.06064 .02947	31 38	4.11	.0001
Op. A' vs Op. B	.1503 .1830	34 49	1.96	.05	.02625 .02673	24 52	.1983	.20
Op. A' bs Op. C	.1503 .1130	34 61	2.22	.05	.02625 .02947	24 38	1.38	.10
Op. B vs Op. C	.1830 .1130	49 61	5.38	.00001	.02673 .02947	52 38	1.01	.20

Operator A and Operator B closer together, and their means in the modified cycle time distributions failed to be significantly different at the 0.05 level. The means of Operator A did not differ significantly on either of the two days she was observed.

Standard Deviation of Raw and Modified Cycle Times.--The standard deviation in minutes for the production of one item per operator ranged from 0.01200 to 0.01892 for raw cycle times and from 0.01097 to 0.01560 for modified cycle times. This gave a ratio of largest variation to smallest variation of 1.577 to 1 for raw cycles and 1.422 to 1 for modified cycles. In a similar manner the ratio was 1.394 to 1 for combined periods of raw cycles and 1.349 to 1 for combined periods of modified cycles.

The rankings for the standard deviations as derived from Tables 1 and 2 were:

	Op. A	Op. A'	Op. B	Op. C
	Raw Cycle Time Distributions			
Period 1	3	1	4	2
Period 2	2	1	4	3
Combined Periods	3	1	4	2
	Modified Cycle Time Distributions			
Period 1	2	1	4	3
Period 2	2	1	4	3
Combined Periods	2	1	4	3

(Lowest ranking equals least standard deviation.)

This provides relationship with production rankings only in the case of Operator A', but does not resemble production or mean rankings otherwise. Hence it does not necessarily follow in this study that the operators with the smaller standard deviations will achieve the higher production that one might expect. The rankings for the combined period standard deviations for modified cycle time distributions are identical to the rankings of the number of internal delays during combined periods.

The grand distribution standard deviations for all operators were 0.01470 for raw cycle times, and 0.01146 for modified cycle times. Standard deviations for individual operator's combined periods were compared against these grand distribution standard deviations by establishing 95 per cent confidence limits, and all operators differed significantly except the standard deviations of raw cycle times for Operators A and C and the standard deviations of modified cycle times for Operator C. These confidence limits are presented in Table 7. Operator C, whose standard deviation did not differ significantly from the standard deviation of the grand distribution in either hour, had the poorest production record.

The distribution standard deviations for combined periods were tested against each other for significance. The levels of significance are shown in Table 8. The elimination of cycles containing internal delays from the distributions did not tend to bring the standard deviations closer together in all instances. Operators A and C had no significant difference at the 0.05 level, between their distribution standard deviations for raw cycle times.

Table 7. 95% Confidence Limits for Standard Deviations of Grand Distributions for all Operators and Distributions of Combined Periods for Individual Operators

Distributions	Confidence Limits	N
	Raw Cycle Distributions	
Grand	.016104 < .01641 < .016716	5492
Op. A	.015352 < .01595 < .016548	1369
Op. A'	.012912 < .01340 < .013888	1446
Op. B	.017983 < .01868 < .019377	1380
Op. C	.015230 < .01584 < .016450	1297
	Modified Cycle Distributions	
Grand	.013027 < .01328 < .013533	5347
Op. A	.011430 < .01188 < .012330	1338
Op. A'	.010634 < .01104 < .011446	1422
Op. B	.014323 < .01489 < .015457	1328
Op. C	.012781 < .01330 < .013819	1259

Table 8. Significance of Differences Between Distribution Standard Deviations

Operator	S.D.	N	F Value	Level of Significance	S.D.	N	F Value	Level of Significance
	Raw Cycle Distributions				Modified Cycle Distributions			
Op. A vs Op. A'	.01595 .01340	1369 1446	1.416	.001	.01188 .01104	1338 1422	1.157	.05
Op. A vs Op. B	.01595 .01868	1369 1380	1.371	.001	.01188 .01489	1338 1328	1.571	.001
Op. A vs Op. C	.01595 .01584	1369 1297	1.014	.10	.01188 .01330	1338 1259	1.254	.005
Op. A' vs Op. B	.01340 .01868	1446 1380	1.944	.001	.01104 .01489	1422 1328	1.819	.001
Op. A' vs Op. C	.01340 .01584	1446 1297	1.398	.001	.01104 .01330	1422 1259	1.451	.001
Op. B vs Op. C	.01868 .01584	1380 1297	1.391	.001	.01489 .01330	1328 1259	1.254	.005
	External Delay Distributions				Internal Delay Distributions			
Op. A vs Op. A'	.09817 .08151	47 34	1.45	.10	.04056 .00696	31 24	33.99	.001
Op. A vs Op. B	.09817 .06350	47 49	2.39	.005	.04056 .01410	31 52	8.28	.001
Op. A vs Op. C	.09817 .07287	47 61	1.81	.025	.04056 .01146	31 38	12.53	.001
Op. A' vs Op. B	.08151 .06350	34 49	1.65	.05	.00696 .01410	24 52	4.11	.001
Op. A' vs Op. C	.08151 .07287	34 61	1.25	.10	.00696 .01146	24 38	2.71	.01
Op. B vs Op. C	.06350 .07287	49 61	1.32	.10	.01410 .01146	52 38	1.51	.05

Measures of Skewness and Peakedness.--All measures of skewness and peakedness for combined periods of the individual operators were significantly different from normal. The level of significance is shown in Table 9. Rankings of these measures are given as follows:

Skewness

Op. A	Op. A'	Op. B	Op. C
Raw Cycles			
4	3	2	1
Modified Cycles			
1	3	4	2

Peakedness

Op. A	Op. A'	Op. B	Op. C
Raw Cycles			
4	3	2	1
Modified Cycles			
1	4	3	2

(Lowest ranking equals least measure.)

The order of rank for measures of skewness and peakedness for raw cycle time distributions is exactly opposed to the order of rank for distribution means of both raw and modified cycle times for combined periods.

The values of skewness of hourly distributions of modified cycle times ranged from 0.5181 to 1.0385 per hour for individual operators with a mean of 0.7121 and a standard deviation of 0.1646, for the individual values. Operator A' was the only one to have both her hourly values for skewness remain fairly close to the mean value.

Table 9. Significance of Differences From the Normal Curve for Distribution Measures of Skewness g_1 and Peakedness g_2

Operator	g_1	N	Z value	Level of Significance	g_2	N	Z value	Level of Significance
				Raw Cycle Distributions				
Op. A	2.9819	1369	45.17	All	16.8131	1369	126.93	All
Op. A'	2.1285	1446	33.02	values	9.9862	1446	77.49	values
Op. B	1.8900	1380	28.73	are	6.7873	1380	51.45	are
Op. C	1.5735	1297	23.08	.00001	5.8866	1297	43.27	.00001
				Modified Cycle Distributions				
Op. A	.5845	1338	8.70	All	.8199	1338	6.12	All
Op. A'	.8019	1422	12.35	values	1.7214	1422	13.25	values
Op. B	.8596	1328	12.80	are	1.7158	1328	12.77	are
Op. C	.5949	1259	8.62	.00001	.9385	1259	6.79	.00001
				External Delay Distributions				
Op. A	.4818	47		.05	-.9635	47		*
Op. A'	1.2130	34		*	.7025	34		*
Op. B	.1588	49		.05	-.5433	49		*
Op. C	1.3056	61		*	1.6054	61		*
				Internal Delay Distributions				
Op. A	.7309	31		*	-.8522	31		*
Op. A'	-.7300	24		.05	-.7379	24		*
Op. B	.8792	52		.05	.4103	52		.05
Op. C	.8375	31		*	-.0813	38		.05

*Tables of significance not effective, judgement withheld. Values of g_1 and g_2 above 1.2 possibly are significant.

The values of peakedness of hourly distributions of modified cycle times ranged from 0.5821 to 2.3274 per hour for individual operators with a mean of 1.2762 and a standard deviation of 0.5784 for the individual values. Operator C was the only one to have both her hourly values for peakedness remain fairly close to the mean value.

The measures of skewness and peakedness of the grand distribution of modified cycle times were 0.6783 and 1.2423 respectively, significantly different from normal.

Delay Parameters.--The parameters for the distributions of delay times were based on samples of less than 100 for the combined periods. No results were determined for individual periods as the samples would have been too small for reaching any valid conclusions.

The distribution means of external delay times ranged from 0.1130 to 0.1830 with a grand distribution mean of 0.1543. The distribution means of internal delay times ranged from 0.02625 to 0.06064 with a grand distribution mean of 0.03462. The rankings of the distribution means were:

Op. A	Op. A'	Op. B	Op. C
	External Delays		
3	2	4	1
	Internal Delays		
4	1	2	3

(Lowest ranking equals least mean.)

These do not resemble the rankings for number of delays, or production, or cycle means.

The grand mean of external delay times is significantly different from the grand mean of internal delay times and both are significantly different from the grand mean for modified cycle times distribution.

All delay time distribution means for individual operators were significantly different from the means of the grand delay time distributions except for the external delay time means for Operators A and A'.

The results of testing each external delay time distribution mean against every other external delay time distribution mean have been presented in Table 6, together with similar results for internal delay time distributions. It is interesting to note in Table 6 that a few very long internal delays of Operator A caused her mean to differ very significantly when tested against the other operators, none of which had internal delays longer than 0.07 minutes.

The standard deviations of external delay time distributions ranged from 0.06350 to 0.09817 with a grand distribution standard deviation of 0.08493. Internal delay time distributions had standard deviations ranging from 0.00696 to 0.04056 with a grand distribution value of 0.02552. The rankings of the distribution standard deviations were:

Op. A	Op. A'	Op. B	Op. C
	External Delays		
4	3	1	2
	Internal Delays		
4	1	3	2

(Lowest ranking equals least standard deviation.)

The grand standard deviation for external delay times is significantly different from that of the internal delay times, and both are significantly different from the grand standard deviation of the modified cycle time distribution.

The results of testing each external delay time distribution standard deviation against every other external delay time distribution standard deviation have been presented in Table 8, together with similar results for internal delay time distributions.

The tests for difference from normality for measures of skewness and peakedness of delays did not show a significant difference from normal in any instance where the sample size was large enough to justify drawing conclusions from these tests.

Analysis of Variance.--The analysis of variance of means of the hourly cycle time distributions revealed that the differences between operators were significant at the 0.001 level. It also revealed that the differences between raw cycle means and modified cycle means were significant at the 0.01 level, although this was not as significant as the effect found between operators. The difference between periods was significant at the 0.025 level. There was a significant interaction between periods and operators at the 0.025 level.

A similar analysis of the variance of standard deviation of the cycle time hourly distributions showed that the differences between operators was significant at the 0.001 level and that there was a high degree of difference between raw and modified cycles at the 0.001 level. However, there were no significant differences between periods and no significant interactions.

The analysis of variance of production per hour revealed that differences between operators were significant at the 0.001 level. The difference between total production per hour and modified hourly production with items containing internal delay times removed was significant at the 0.001 level. The interaction between hourly periods and operators was significant at the 0.025 level, but the effect of differences between the 1st and 2nd hour was not significant. No other interactions were significant.

The mean squares and levels of significance for these three analyses are tabulated in Table 10.

Table 10. Significance of Sources of Variation as Derived from Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value	Level of Significance
			Production N		
Type of Distribution C (Raw Cycles, Modified Cycles)	1	1,314.0	1,314.0	194.4	.001
Work Period P (1st Hour, 2nd Hour)	1	14.0	14.0	.8	.10
Operator O (A, A', B, C)	3	12,173.2	4,057.7	716.1	.001
C x P Interaction	1	3.2	3.2	.4	.10
C x O Interaction	3	107.2	35.7	4.3	.10
P x O Interaction	3	491.2	163.7	19.5	.025
C x P x O Error Term	3	25.2	8.4		
Total	15	14,128.0			
			Means $\bar{X}$		
Type of Distribution C (Raw Cycles, Modified Cycles)	1	102,240.0	102,240.0	13.9	.01
Work Period P (1st Hour, 2nd Hour)	1	50,512.5	50,512.5	9.3	.025
Operator O (A, A', B, C)	3	1,895,602.7	631,867.6	116.5	.001
C x P Interaction	1	945.7	945.7	.4	.10
C x O Interaction	3	5,533.7	1,844.6	2.3	.10
P x O Interaction	3	160,459.2	53,486.4	22.5	.025
C x P x O Error Term	3	7,115.1	2,371.7		
Total	15	2,222,408.9			
			Standard Deviation S_x		
Type of Distribution C (Raw Cycles, Modified Cycles)	1	365,420.3	365,420.3	142.4	.001
Work Period P (1st Hour, 2nd Hour)	1	4,096.0	4,096.0	1.6	.10
Operator O (A, A', B, C)	3	492,429.0	164,143.0	63.9	.001
C x P Interaction	1	702.2	702.2	.3	.10
C x O Interaction	3	37,838.7	12,612.9	5.2	.10
P x O Interaction	3	29,747.0	9,915.6	4.1	.10
C x P x O Error Term	3	7,284.8	2,428.3		
Total	15	937,518.0			

CHAPTER IX

CONCLUSIONS AND RECOMMENDATIONS

Nature of the Results of the Study.--The general investigative nature of this study wherein two purposes were combined into one experimental design complicated the determination of conclusions that deserve no further investigation. The purposes of the study however, were achieved.

The parameters of the work-time distributions obtained substantiated in all the investigated areas the previous research done by a series of investigators at Georgia Tech. It can now be stated without skepticism that the work-time distribution for the particular type of work studied does depart from the normal curve form. Removing variables from the distribution does tend to reduce the measures of this departure, but not to the extent that the distribution begins in any manner to resemble the normal curve.

The delay time distributions did not apparently depart from normal or resemble in any manner the work-time distributions. The sample sizes from which the delay time distributions were obtained were small and this limitation should be overcome at the first opportunity. Within this limitation, however, the previous work of Davis and Josselyn are only partially substantiated. Internal delays do exist in considerable quantity, even though the external delays are significantly greater. The means of the hourly work-time distributions tend to vary from hour to hour for individual operators, while the standard deviations for individual operators do not differ significantly from period to period. This latter set of conclusions may be of value to those performing specific research in the field because it defines the question of an operator's optimum physiological limit. The level of performance does shift as they intimate, but this study does not demonstrate a changing spread in variation about the level the operator seeks to maintain. This may at least be further proof that an operator does not deviate further and further from a standard method as the work day progresses.

Various other relationships and areas for further investigation were obtained from this study. They are listed in the following sections.

Conclusions.--The following specific conclusions are based on analysis of a manual, repetitive, worker controlled, short cycled operation. All conclusions are based on cycle time and delay time frequency distributions obtained from the observation of three workers for two consecutive periods one hour long, with a replicate observation period for one of these three operators. The minimum sample size of work cycles obtained in any one hour period was 647 cycles.

(1) For an operation of the type studied, the work-time distribution of the cycles remaining after all cycles containing internal delay have been removed is positively skewed, eight values of g_1 having an average of about 0.7121 with a standard deviation of 0.1646 for the individual values. The peakedness of this distribution is significantly greater than that of a Normal Curve, eight values of g_2 having an average of 1.2762 with a standard deviation of 0.5784 for the individual values.

(2) For an operation of the type studied, the values of the distribution means, standard deviations, measures of skewness, and measures of peakedness decrease when cycles containing internal non-work time are removed from the study.

(3) For an operation of the type studied, the mean and standard deviation of the grand distribution of raw cycle times are significantly

different from the mean and standard deviation of the grand distribution remaining when all cycles containing internal delays have been removed.

(4) For an operation of the type studied, the mean and the standard deviation of the grand distribution of external delay times are significantly greater than the mean and the standard deviation of the grand distribution of internal delay times; and the total number of external delays observed for all operators was larger than the total number of internal delays observed.

(5) For an operation of the type studied, the standard deviations of each operator's work-time distribution did not vary significantly between the first and second hour of the observation period.

These conclusions relate directly to the five specific objectives listed in Chapter IV. The following additional conclusions were observed as the analysis of data was performed.

(6) Ranking of the distribution means and ranking of the distribution standard deviations of each operator for periods of one hour or longer are not valid indicators of operator performance in terms of production accomplished.

(7) Elimination of cycles containing variables from a study of this nature will tend to reduce the level of significance of the difference between means of the distributions of cycle times for the individual operators.

(8) In this limited study, the ranking technique for large sample sizes indicated that an inverse relationship existed between the raw cycle time distribution means and measures of skewness and peakedness.

(9) All measures of skewness and peakedness for the distributions of raw cycle times and distributions of modified cycle times differ from similar parameters for the Normal Curve.

(10) For an operation of the type studied, the means of each operator's work-time distribution varied significantly between the first and second hour of the observation period.

Limitations.--The aforementioned results must be viewed in the light of the following limitations:

The selection of operators was not random. Only three operators were observed. The replicate observation of Operator A was treated as if it were a fourth operator. The operators appeared to be highly motivated.

The observation period was only two hours long, and occurred during the first three hours of the work day. The effect of a continuous period of observation using only one observer may have introduced error of an anticipatory nature. The operation observed was extremely short in cycle length.

The number of delays observed was extremely small during individual hours. Delays were only classified according to two general categories based on the location of their occurrence in relation to cycle times.

The instrument used to gather the data has not been evaluated as to performance as a time study recorder.

Recommendations.--Certain basic recommendations can be made regarding this study in terms of future investigations in this area of work measurement. In addition, certain relationships were revealed during the analysis of data that were too weak to result in valid conclusions. They might possibly prove of future interest if scientifically investigated.

The basic recommendations concern possible continuation of the present study and are listed as follows:

Random selection of operators to be observed.

Observation of a larger number of operators.

Observation of operators throughout a complete work day or shift.

Selection of an operation having a longer cycle time.

Selection of an operation where the general ratio of production to number of delays is known in advance and is a smaller number than the ratio in this study.

Investigation of the shape of the distributions obtained, through curve fitting techniques.

Investigation of the correlation of the rankings of the parameters obtained in terms of performance relationships.

A study should be made concerning the ratio of production to the number of delays in a variety of jobs. This ratio possibly is inversely proportional to the cycle length.

A study should be made of the ratio of the hourly production of the best worker to the hourly production of the worst worker in comparison to the ratio of the largest mean cycle time per hour to the smallest mean cycle time per hour. The value of these ratios appeared to be similar in this study.

It might be possible to estimate or rate performance by investigating how often a worker's mean hourly production exceeds one standard deviation either side of the grand mean hourly production for all workers.

Investigations of correlation might possibly be of value in two instances. In the first, the number of cycles accomplished per hour that do not contain variables may correlate with the number of external delays per hour. In the second, the size of the standard deviation of the operator's cycles remaining after variable cycles have been removed may correlate with the number of internal delays for each observation period.

Possible Applications of the Study.--The work-time distribution has been more clearly defined in this presentation. It may be possible to derive the particular equation of this distribution for the type of work under consideration. If this is accomplished, prediction of production will become more accurate. Rating procedures may be modified drastically.

Should further investigation verify the inverse relationship between cycle time distribution means and measures of skewness and peakedness, a handy tool for measuring motivation might possibly result.

If the distribution of work-times do not resemble those of delay-times then attempts to measure performance by delay counts or delay distribution parameters, will become invalid.

It has been clearly illustrated in this study that all personal delays do not necessarily occur between cycles. This should cause a revision in certain current systems of obtaining delay allowances.

Finally, it is apparent that the mean time or level of performance is a much more valuable method of estimating a worker's activity trend throughout the day than is any determination of the deviation from this level within a sample observation period.

It is hoped that continuing research of a specific or general nature will further the development of work measurement into a truly scientific area of endeavor.

APPENDIX A

SIMO CHART

METHOD PRESENT CHART BY ROGERS
OPERATION ASSEMBLY DATE CHARTED 3-27-56
PART NAME CAP FOR T-200 BALL POINT PEN

LEFT HAND DESCRIPTION	SYMBOL	TIME	TIME	SYMBOL	RIGHT HAND DESCRIPTION
Cap Assembly on Fixture	A	4	6	UD	Wait on Cap Assembly
Cap Assembly	RL	2			
To Alignment Sleeve	TE	12	12	UD	Wait on Staking Operation
Alignment Sleeve	ST	6	2	G	Finished Assembly
			1	RL	" "
			3	TL	Finished Assembly to disposal box
			1	RL	Finished Assembly into disposal box
Alignment Sleeve	G	4	3	TE	To Latch Springs
To Fixture	TL	3	2	ST	Latch Spring
Alignment Sleeve on Fixture	P	3	3	G	Latch Spring
Alignment Sleeve on Fixture	A	3	6	P	Latch Spring in Hand
Alignment Sleeve	RL	1			
To Plunger	TE	3	6	UD	Wait For Left Hand
Plunger	ST	3			
Plunger	G	4	6	TL	Latch Spring to Meet Left Hand
Plunger to Right Hand	TL	4			
Plunger For Latch Spring	P	2	3	P	Latch Spring in Plunger
Plunger	H	6	6	A	Latch Spring in Plunger
Plunger	RL	3	3	G	Plunger
To Cap Assembly	TE	3	4	TL	Plunger to Fixture
Cap Assembly	ST	2			
Cap Assembly	G	3	5	P	Plunger in Fixture
Cap Assembly to Fixture	TL	6	5	A	Plunger on Fixture
Cap Assembly on Fixture	P	1	1	RL	Plunger
LEFT HAND SUMMARY					RIGHT HAND SUMMARY
23.1 %	TE	18	24	UD	30.8 %
16.7 %	TL	13	14	P	18.0 %
14.1 %	ST	11	13	TL	16.7 %
14.1 %	G	11	11	A	14.1 %
8.9 %	A	7	8	G	10.0 %
7.7 %	RL	6	3	TE	3.8 %
7.7 %	P	6	2	RL	2.6 %
7.7 %	H	6	2	ST	2.6 %
			1	DA	1.4 %

Fig. 1 Therblig Analysis of Observed Assembly

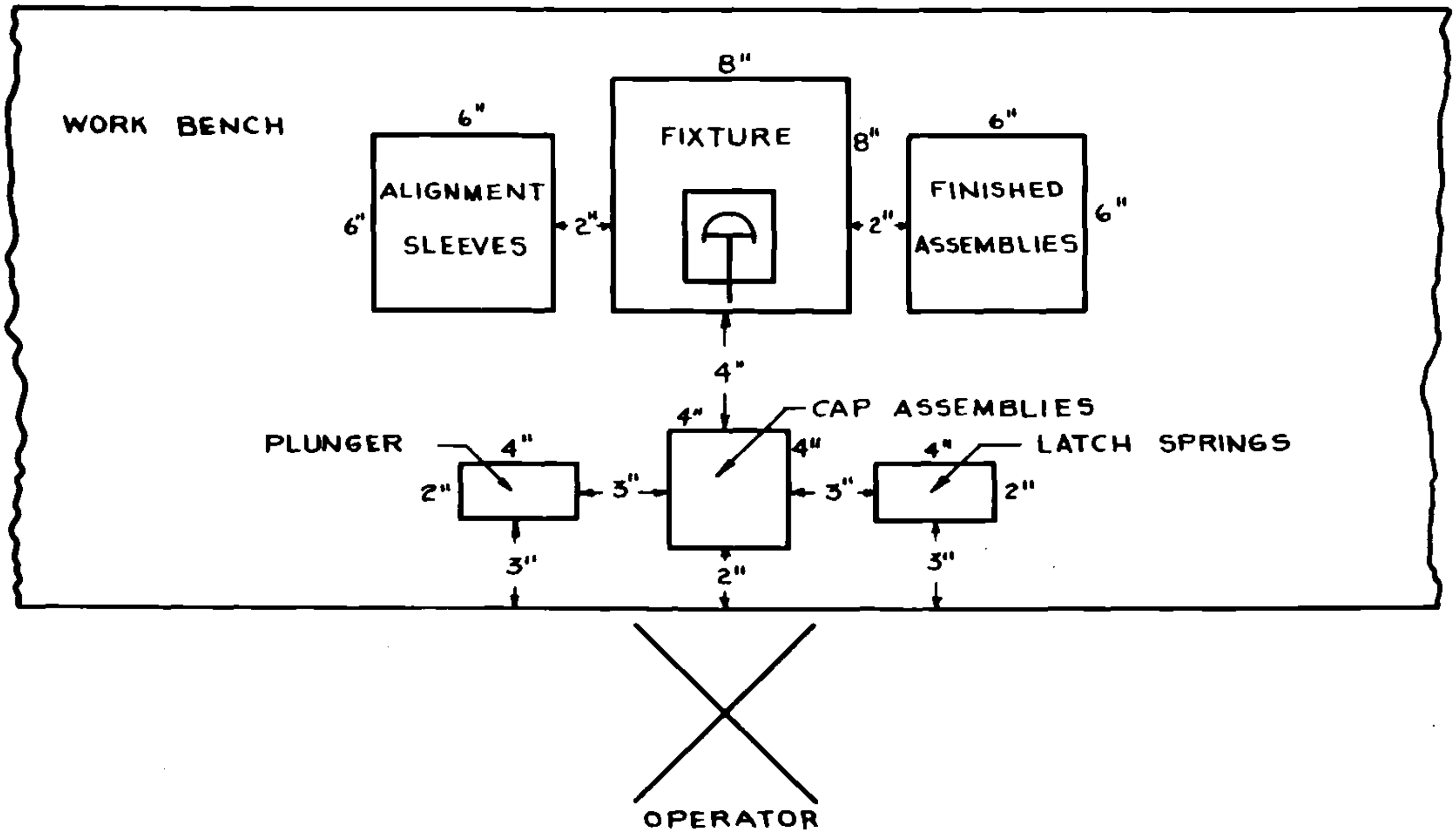

Fig. 2 Layout of Workplace for Observed Assembly

APPENDIX B

MILLIMINUTE TIMER

Georgia Institute of Technology

This system comprises the following units:

1. A Pulse Generator whose output is 16.6 cycles per second derived in the following manner:

   A phase shift oscillator is locked in at 300 cycles by a 60 cycle synchronizing signal. The output of this oscillator is fed into a Schmidt trigger whose output is divided by a ternary divider followed by a second ternary divider, bringing the frequency to 33.3 cycles per second. A binary divider produces 16.6 cycles per second which is shaped by a delay multivibrator. Both the negative-going and positive-going outputs of this multivibrator are used--the negative to operate the first binary stage of the four-stage electronic counter; the positive is used to synchronize the readout command with the pulse generator to prevent error in counting pulses.

2. Electronic Counter: This is a four-stage binary counter which, by means of feedback, produces a binary coded decimal number. Every tenth pulse is applied through a buffer tube to an overflow relay which supplies a pulse to a solenoid in the Clary machine, resulting in the tripping of a clutch to enter a one in the tens order. When reading out, all four binary stages are examined for a zero or one condition; and, by means of a relay translating matrix, the appropriate decimal digit is entered in the units order of the Clary machine.

3. Buffer Stage: These tubes act to convert the high impedance output of the electronic counter stages and the delay multivibrator in the pulse generator into signals suitable for operating relays.

4. Relay Controls: Four of the relays are used for the translating matrix (K-5, K-6, K-7, K-8), one for tens overflow (K-4), and readout control (K-1, K-2, K-3).

5. Power Supply: Delivers + 300, + 150, - 60 and - 15 volts.

Description of Read-Out Operation: Depressing the read-out switch on the Clary machine locks up relay K-3. If this occurs during the 30 milliseconds period that the delay multivibrator is positive, relay K-2 will be pulled which connects matrix buffer cathodes to ground and causes operation of matrix relays in accordance with numbers standing in electronic counter. At the same time, K-1 is operated through contacts on K-2 and the following takes place:

A. The counter is reset due to K-2 and K-1 being operated at the same time. (Reset time is approximately two minutes.)

B. Matrix relays are locked in position.

C. Ground is applied to total solenoid and input of decoding matrix resulting in energization of a unit solenoid in the Clary machine.

D. K-1 releases K-2 and K-3.

The machine now cycles and restores circuit to normal. It can be seen that the counter was in a position to start counting with the next pulse from the generator.

If overflow should occur at the same time as a read-out command, the overflow operation will take precedence over the read-out command. The read-out command will be effected as soon as overflow is completed and a zero will be printed in units order.

MILLIMINUTE TIMER and PRINTER

OPERATING INSTRUCTIONS

1. Plug printer into convenience outlet at rear of timer cabinet.

2. Turn A.C. switch on. This applies power to all equipment, including printer.

3. Allow five minutes for warm-up.

4. Throw switch on right of panel to "On". This connects output of milliminute generator to electronic counter in the timer cabinet. The lamp above this switch will flash every ten milliminutes. The switch should be "Off" when timing runs are not being made.

5. Equipment is now ready for use.

6. To start a timing element press the "read-out" button momentarily.

7. To prepare to record a timing element put element number in keyboard.

8. To complete a timing element press "read-out" button. The time interval printed will be the time between the first and second operations of the button.

9. If the timing element is reduced by more frequent pressing of the button, the limit is reached when the button is held down continuously. With this operation the time recorded will be the repeat cycling time of the machine. This may vary slightly due to variations in the action of the governor. However, the time element printed for the repeat cycling time will be timed accurately by the timing unit.

10. Maximum timing element is 99.999 minutes. If this is exceeded, the time will automatically restart at zero.

11. To check timing accuracy an oscilloscope may be placed across the terminals marked "ctr. input test" in the center of the panel. This permits testing of the output of the pulse generator for amplitude and frequency. By feeding a signal from this terminal to an exterminal electronic counter, the count during a run may be compared with the number printed on the tape.

12. Single step operation of electronic counter (Detection TU-100-P) may be effected by operating push button on the right top of pulse generator sub-chassis.

NOTE: The A.C. power line contains a 3-amp fuse.

The D.C. to the solenoids in the machine contains a 1/4 amp "slo-blo" fuse. Should it be necessary to replace this fuse do not exceed this rating.

The equipment has been tested satisfactorily with regard to accuracy between 105 and 130 volts A.C. line.

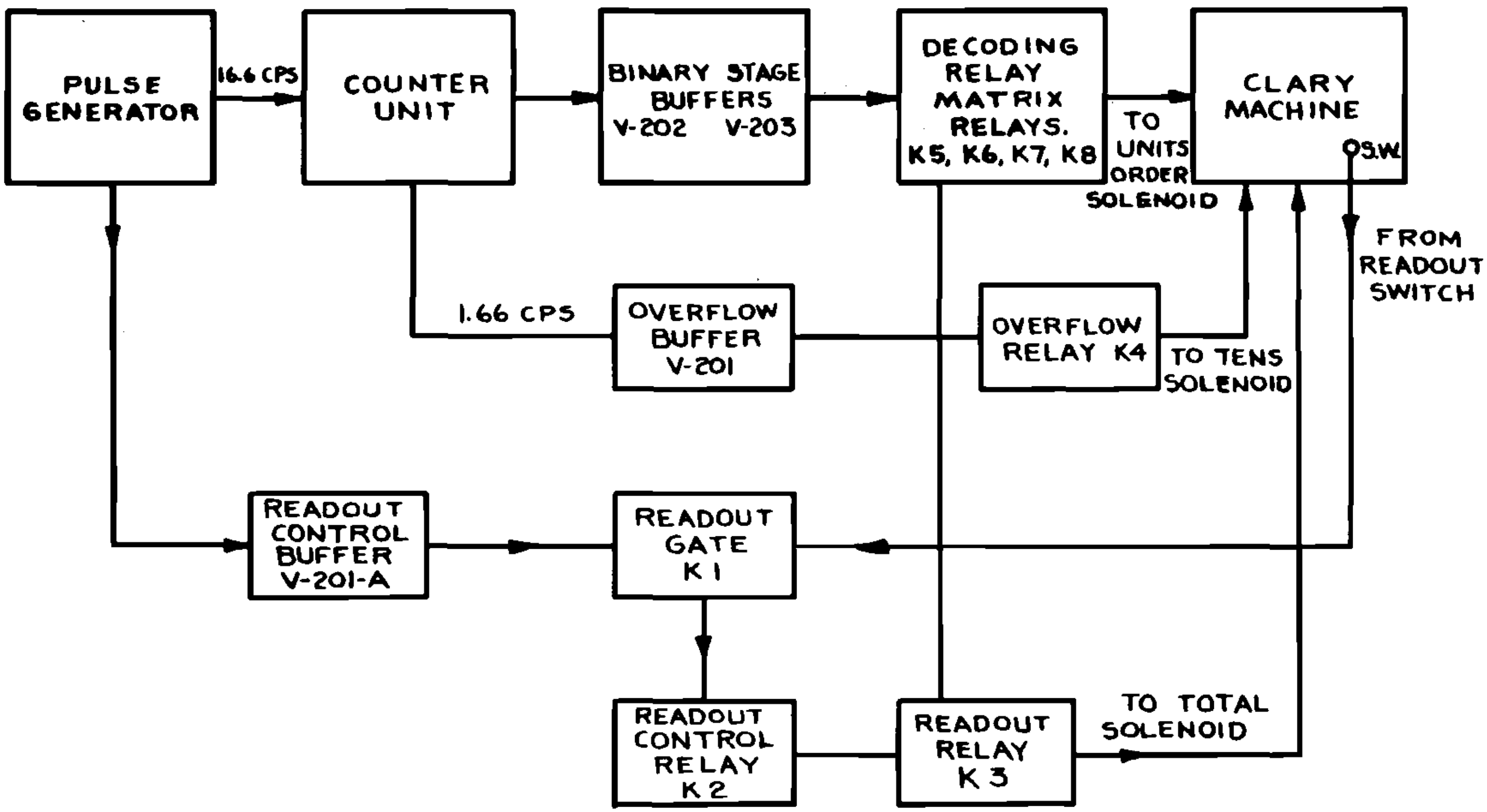

Fig. 3 Block Diagram of Milliminute Timer

APPENDIX C

Table 11. Basic Frequency Distribution for
Operator A, 1st Hour

Time Minutes	Raw Cycles	Mod. Cycles	Ext. Del.	Int. Del.
.01				
.02				1
.03		1	1	3
.04	1	1	1	6
.05	14	14		1
.06	58	58	2	2
.07	242	242		
.08	224	223	1	
.09	77	75	2	
.10	43	41	2	
.11	18	17	1	2
.12	8	5	1	1
.13	1		1	
.14	1			1
.15			2	
.16				
.17	1			
.18	3		1	
.19				
.20	1		1	
.21				
.22	1			
.23				
.24				
.25				
.26			1	
.27				
.28				
.29				
.30				
.31			1	
.32				
.33				
.34			2	
.35				
.36				
.37				
.38				
.39			1	
TOTALS	693	676	21	17

Table 12. Basic Frequency Distribution for Operator A, 2nd Hour

Time Minutes	Raw Cycles	Mod. Cycles	Ext. Del.	Int. Del.
.01				2
.02				2
.03				2
.04			2	1
.05	7	7		1
.06	34	34		
.07	224	224		
.08	226	226	1	
.09	120	117		2
.10	41	39	1	1
.11	13	13		1
.12	3	2	2	
.13	1		2	
.14	1		2	2
.15	1		2	
.16			1	
.17	1		1	
.18	1		1	
.19	2		1	
.20	1			
.21				
.22				
.23				
.24				
.25			1	
.26			2	
.27			1	
.28			2	
.29				
.30			1	
.31			1	
.32				
.33			1	
.34				
.35			1	
.36				
.37				
.38				
.39				
TOTALS	676	662	26	14

Table 13. Basic Frequency Distribution for Operator A', 1st Hour

Time Minutes	Raw Cycles	Mod. Cycles	Ext. Del.	Int. Del.
.01				
.02				5
.03				6
.04			2	2
.05	8	8		
.06	27	27		
.07	217	217	2	
.08	288	288	2	
.09	114	114		
.10	37	35	2	
.11	12	9		
.12	7	6		
.13	2	1	3	
.14	2		1	
.15			3	
.16	2		1	
.17	2			
.18			1	
.19				
.20				
.21				
.22				
.23			1	
.24				
.25				
.26				
.27				
.28				
.29				
.30				
.31				
.32				
.33				
.34			1	
.35				
.36				
.37				
.38				
.39				
TOTALS	718	705	19	13

Table 14. Basic Frequency Distribution for
Operator A', 2nd Hour

Time Minutes	Raw Cycles	Mod. Cycles	Ext. Del.	Int. Del.
.01				
.02				7
.03				3
.04			1	1
.05	4	4		
.06	40	40	1	
.07	248	248		
.08	270	270	2	
.09	101	101		
.10	35	34		
.11	18	16	1	
.12	4	3	2	
.13	4	1		
.14			2	
.15	1		1	
.16	1		1	
.17	1			
.18	1			
.19				
.20				
.21				
.22				
.23				
.24				
.25				
.26			1	
.27				
.28				
.29			1	
.30				
.31			1	
.32				
.33				
.34				
.35				
.36			1	
.37				
.38				
.39				
TOTALS	728	717	15	11

Table 15. Basic Frequency Distribution for
Operator B, 1st Hour

Time Minutes	Raw Cycles	Mod. Cycles	Ext. Del.	Int. Del.
.01				7
.02				12
.03				3
.04	1	1		5
.05	16	15		3
.06	79	77	1	
.07	182	182	1	
.08	196	195		
.09	94	94		
.10	55	52	1	
.11	28	23		
.12	12	8	3	
.13	4	3	2	
.14	8	5	2	
.15	5		2	
.16	5	1	4	
.17			2	
.18	1		2	
.19			1	
.20			2	
.21				
.22			1	
.23			1	
.24				
.25				
.26			1	
.27				
.28				
.29				
.30				
.31				
.32				
.33				
.34			1	
.35				
.36				
.37				
.38				
.39				
TOTALS	686	656	27	30

Table 16. Basic Frequency Distribution for Operator B, 2nd Hour

Time Minutes	Raw Cycles	Mod. Cycles	Ext. Del.	Int. Del.
.01				4
.02				5
.03				8
.04	2	2		2
.05	11	11		1
.06	81	81		1
.07	204	203	2	1
.08	178	178	1	
.09	113	112	1	
.10	55	55	1	
.11	24	20		
.12	9	8	1	
.13	5	1	1	
.14	4	1		
.15	1			
.16	2		1	
.17			1	
.18	2		2	
.19			2	
.20	3			
.21				
.22				
.23			1	
.24			2	
.25			2	
.26			2	
.27			1	
.28				
.29				
.30			1	
.31				
.32				
.33				
.34				
.35				
.36				
.37				
.38				
.39				
TOTALS	694	672	22	22

Table 17. Basic Frequency Distribution for Operator C, 1st Hour

Time Minutes	Raw Cycles	Mod. Cycles	Ext. Del.	Int. Del.
.01				1
.02				7
.03			1	2
.04			2	3
.05	1	1	4	2
.06	6	6	10	1
.07	65	65	3	
.08	198	198	1	
.09	179	179	1	
.10	114	114	1	
.11	54	51		
.12	17	13		
.13	3	2	2	
.14	4	2		
.15	1			
.16	1		1	
.17			2	
.18	3			
.19				
.20	1			
.21			1	
.22			1	
.23			1	
.24				
.25				
.26				
.27				
.28				
.29				
.30				
.31				
.32				
.33				
.34				
.35				
.36				
.37				
.38				
.39				
TOTALS	647	631	31	16

Table 18. Basic Frequency Distribution for Operator C, 2nd Hour

Time Minutes	Raw Cycles	Mod. Cycles	Ext. Del.	Int. Del.
.01				
.02				9
.03			1	9
.04			1	2
.05	2	2	4	2
.06	22	22	2	
.07	122	121	3	
.08	195	195	1	
.09	178	176		
.10	73	70	2	
.11	25	21	2	
.12	15	15	1	
.13	7	4	1	
.14	7	2	1	
.15	2		4	
.16	1			
.17	1			
.18			2	
.19				
.20				
.21				
.22				
.23				
.24			1	
.25			1	
.26			1	
.27			1	
.28				
.29				
.30				
.31				
.32				
.33				
.34				
.35				
.36				
.37			1	
.38				
.39				
TOTALS	650	628	30	22

Table 19. Basic Frequency Distribution for Operator A, Combined Periods

Time Minutes	Raw Cycles	Mod. Cycles	Ext. Del.	Int. Del.
.01				2
.02				3
.03			1	5
.04	1	1	3	7
.05	21	21		2
.06	92	92	2	2
.07	466	466		
.08	450	449	2	
.09	197	192	2	2
.10	84	80	3	1
.11	31	30	1	3
.12	11	7	3	1
.13	2		3	
.14	2		2	3
.15	1		4	
.16			1	
.17	2		1	
.18	4		2	
.19	2		1	
.20	2		1	
.21				
.22	1			
.23				
.24				
.25			1	
.26			3	
.27			1	
.28			2	
.29				
.30			1	
.31			2	
.32				
.33			1	
.34			2	
.35			1	
.36				
.37				
.38				
.39			1	
TOTALS	1369	1338	47	31

Table 20. Basic Frequency Distribution for
Operator A', Combined Periods

Time Minutes	Raw Cycles	Mod. Cycles	Ext. Del.	Int. Del.
.01				
.02				12
.03				9
.04			3	3
.05	12	12		
.06	67	67	1	
.07	465	465	2	
.08	558	558	4	
.09	215	215		
.10	72	69	2	
.11	30	25	1	
.12	11	9	2	
.13	6	2	3	
.14	2		3	
.15	1		4	
.16	3		2	
.17	3			
.18	1		1	
.19				
.20				
.21				
.22				
.23			1	
.24				
.25				
.26			1	
.27				
.28				
.29			1	
.30				
.31			1	
.32				
.33				
.34			1	
.35				
.36			1	
.37				
.38				
.39				
TOTALS	1446	1422	34	24

Table 21. Basic Frequency Distribution for Operator B, Combined Periods

Time Minutes	Raw Cycles	Mod. Cycles	Ext. Del.	Int. Del.
.01				11
.02				17
.03				11
.04	3	3		7
.05	27	26		4
.06	160	158	1	1
.07	386	385	3	1
.08	374	373	1	
.09	207	206	1	
.10	110	107	2	
.11	52	43		
.12	21	16	4	
.13	9	4	3	
.14	12	6	2	
.15	6		2	
.16	7	1	5	
.17			3	
.18	3		4	
.19			3	
.20	3		2	
.21				
.22			1	
.23			2	
.24			2	
.25			2	
.26			3	
.27			1	
.28				
.29			1	
.30				
.31				
.32				
.33				
.34			1	
.35				
.36				
.37				
.38				
.39				
TOTALS	1380	1328	49	52

Table 22. Basic Frequency Distribution for Operator C, Combined Periods

Time Minutes	Raw Cycles	Mod. Cycles	Ext. Del.	Int. Del.
.01				1
.02				16
.03			2	11
.04			3	5
.05	3	3	8	4
.06	28	28	12	1
.07	187	186	6	
.08	393	393	2	
.09	357	355	1	
.10	187	184	3	
.11	79	72	2	
.12	32	28	1	
.13	10	6	3	
.14	11	4	1	
.15	3		4	
.16	2		1	
.17	1		2	
.18	3		2	
.19				
.20	1			
.21			1	
.22			1	
.23			1	
.24			1	
.25			1	
.26			1	
.27			1	
.28				
.29				
.30				
.31				
.32				
.33				
.34				
.35				
.36				
.37			1	
.38				
.39				
TOTALS	1297	1259	61	38

Table 23. Basic Frequency Distribution for
Operator A, All Periods

Time Minutes	Raw Cycles	Mod. Cycles	Ext. Del.	Int. Del.
.01				2
.02				15
.03			1	14
.04	1	1	6	10
.05	33	33		2
.06	159	159	3	2
.07	931	931	2	
.08	1008	1007	6	
.09	412	407	2	2
.10	156	149	5	1
.11	61	55	2	3
.12	22	16	5	1
.13	8	2	6	
.14	4		5	3
.15	2		8	
.16	3		3	
.17	5		1	
.18	5		3	
.19	2		1	
.20	2		1	
.21				
.22	1			
.23			1	
.24				
.25			1	
.26			4	
.27			1	
.28			2	
.29			1	
.30			1	
.31			3	
.32				
.33			1	
.34			3	
.35			1	
.36			1	
.37				
.38				
.39			1	
TOTALS	2815	2760	81	55

Table 24. Basic Frequency Distribution for
All Operators, All Periods

Time Minutes	Raw Cycles	Mod. Cycles	Ext. Del.	Int. Del.
.01				14
.02				48
.03			3	36
.04	4	4	9	22
.05	63	62	8	10
.06	347	345	16	4
.07	1504	1502	11	1
.08	1775	1773	9	
.09	976	968	4	2
.10	453	440	10	1
.11	192	170	4	3
.12	75	60	10	1
.13	27	12	12	
.14	27	10	8	3
.15	11		14	
.16	12	1	9	
.17	6		6	
.18	11		9	
.19	2		4	
.20	6		3	
.21			1	
.22	1		2	
.23			4	
.24			3	
.25			4	
.26			8	
.27			3	
.28			2	
.29			2	
.30			1	
.31			3	
.32				
.33			1	
.34			4	
.35			1	
.36			1	
.37			1	
.38				
.39			1	
TOTALS	5492	5347	191	145

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